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13. ABSTRACT (Maximum 200 words) The research objective of this study was to develop an understanding of the cohesive failure of adhesively bonded joints under load and in aggressive environments. Such an understanding could then be used to predict the durability of adhesively bonded joints in humid environments. The problem was to have been approached by first examining the diffusion kinetics and then modeling the deformation and failure behavior as a function temperature and moisture.

Although only one adhesive was to have been considered in the study, the first adhesive had to be abandoned mid-way through the program (after its diffusion characteristics had been studied) when creep deformation experiments revealed an unexceptable degree of scatter due to random shear banding. After some development, a suitable second adhesive was found, but there was not enough time to completely characterize its diffusion, deformation and failure behavior as a function of temperature and moisture.

In the analytical portion of the project, finite element analyses were conducted to optimize various specimens employed in the experimental program. In addition, several thermo-mechanical models for rate-dependent materials with sensitivity to hydrostatic pressure were explored. An extended Prager Drucker plasticity model reproduced the data obtained to date.

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DURABILITY PREDICTIONS FOR ADHESIVELY BONDED JOINTS IN HUMID ENVIRONMENTS

Final Report
EMRL 93-10

G.J. Rodin and K.M. Liechti

September 29, 1993

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EXECUTIVE SUMMARY

The research objective of this study was to develop an understanding of the cohesive failure of adhesively bonded joints under load and in aggressive environments. Such an understanding could then be used to predict the durability of adhesively bonded joints in humid environments. The problem was to have been approached by first examining the diffusion kinetics and then modeling the deformation and failure behavior as a function temperature and moisture.

Since one of the motivations for the study was to be able to predict the durability of light weight bridge structures, the first adhesive that was used in the study was a modified epoxy that had been developed for the Army by Martin Marietta Laboratories. The diffusion kinetics were studied extensively and found to be Fickean in nature with the diffusivity a function of temperature level but not moisture. Optical interference measurements of the thickness change of a sandwiched adhesive layer were used to validate the diffusion model and its finite element implementation. However, the success of this portion of the work was clouded by unsuccessful attempts to characterize the deformation behavior of the adhesive as a function of temperature and humidity. There were large amounts of scatter in tensile creep experiments that were due to multiple shear bands that formed randomly in the specimens. These shear bands initiated at microscopic bubbles that were trapped during the processing of the adhesive. They were impossible to remove due to the high viscosity of the three-part precursor resins that were mixed together to form the adhesive. An in-house program that was conducted at the Materials Technology Laboratory was unsuccessful in improving the processibility of the material and a new adhesive had to be found.

Based on our previous experience, a desirable adhesive would have to be easy to process, have a relatively low glass transition (70°C) and provide strong aluminum/aluminum bonds that would not fail adhesively, particularly in humid environments. A Ciba Geigy product, epoxy resin 502, a modified bisphenol -A, cured with hardener 905, an amido amine, quickly satisfied the first two criteria. However, it did not by itself form a particularly strong bond with the aluminum until a silane coupling agent coupling agent was applied to the aluminum prior to bonding. Some initial moisture diffusion experiments indicated that the diffusion characteristics of the second adhesive were sufficiently different from those of the first one that the whole matrix of diffusion experiments has had to be repeated. At this time, not all conditions have been re-examined and adsorption and desorption have not been reversible, as was the case with the first adhesive. A three-chamber, computer controlled, temperature/humidity facility was developed in order to increase the number of experiments that could be conducted in a given period of time. Three creep frames and extensometers were also developed, with computer data acquisition by the same computer that controls the temperature/humidity chambers.

The analytical aspect of the project has been twofold. First, standard options of the finite element program ABAQUS have been employed to analyze and optimize various specimens involved in the experimental program. Second, several thermo-mechanical models for rate-dependent materials sensitive to humid environments have been explored. The latter task is incomplete at this time, primarily due to the lack of sufficient experimental data. At this point, it is clear that classical plasticity models based on the deviatoric stress are inadequate. This is because the response of the adhesives considered in this work exhibits strong sensitivity to the presence of microscopic voids. As a result, the adhesives behave quite differently in tension and compression so that the hydrostatic stress has to be introduced into the model. To this end, an extended Prager-Drucker plasticity model, as implemented in the ABAQUS, has been studied. The model is capable of reproducing the experimental data that has been obtained to date.

Graduate Student Support

The project has provided support for one PhD student (C.F. Popelar) and two MS students (C.R. Beebe and P.A. Thomas), who have both graduated. Two MS theses have been written:

- C.R. Beebe, "Experimental Methods for Durability Predictions for Adhesively Bonded Joints," MS Thesis, The University of Texas at Austin, December 1992.

- P.A. Thomas, " A Procedural Handbook for Using ABAQUS on the CRAY Y-MP8/864 with Emphasis on Temperature and Moisture Dependent Stress Analysis," MS Thesis, The University of Texas at Austin, May 1993.

No archival papers have yet been published due to the change in adhesive that was made. Nonetheless it is expected that publications will soon result from the work with the second adhesive.